CR-132812

Final Report

for the

ELECTRICALLY SCANNING MICROWAVE RADIOMETER FOR NIMBUS E

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland

1740FR-1

January 1973

AEROJET ELECTROSYSTEMS COMPANY

AZUSA, CALIFORNIA

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In Response to

Contract NAS 5-21115

Article 4B

Prepared by

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FOREWORD

This report covers work performed under Contract NAS 5-21115 during the period 19 February 1970 through 31 December 1972. The work was sponsored by the National Aeronautics and Space Administration's Goddard Space Flight Center, Greenbelt, Maryland. Program technical monitors for this contract have been Mssrs. Brice Miller and Dean Smith of NASA/GSFC.

ABSTRACT

An Electronically Scanning Microwave Radiometer system has been designed, developed and tested by Aerojet ElectroSystems Company's Microwave Systems Department (formerly Aerojet General Corporation's Microwave Division) for measurement of meteorological, geomorphological and oceanographic parameters from NASA/GSFC's Nimbus E satellite. The system is a completely integrated radiometer designed to measure the microwave brightness temperature of the Earth and its atmosphere at a microwave frequency of 19.35 GHz. Calibration and environmental testing of the system have successfully demonstrated its ability to perform accurate measurements in a satellite environment. The successful launch and data acquisition of the Nimbus 5 (formerly Nimbus E) gives further demonstration to its achievement.

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Section 1

INTRODUCTION

The products developed under Contract NAS 5-21115 consisted of the Mass Model, Engineering Model, Protoflight Model and Flight Model of the Electrically Scanning Microwave Radiometer in addition to two each of a bench checkout unit capable of stimulating the input and interrogating the outputs of the radiometer and two bench checkout units capable of providing highly accurate targets for the radiometer. The following sections briefly describe each instrument and provides a reference for the applicable documentation.

Section 2

ELECTRICALLY SCANNING MICROWAVE RADIOMETER

2.1 GENERAL

The Electrically Scanning Microwave Radiometer basically consists of a scanning planar array antenna, Dicke microwave radiometer and post-detection electronics. The antenna is a planar electronically scanned array that scans in one plane. The antenna is coupled to the radiometer which compares the brightness temperature at the antenna to a temperature controlled hot (Dicke) load within the instrument. This comparison generates an analog voltage proportional to the temperature difference which is then quantized and further processed by digital circuitry included in the instrument. The output of the radiometer is a serial ten bit word for each beam position. The gain of the radiometer system is established by comparing a sky reference antenna (cold horn) to the hot load. The system automatically adjusts the gain to a nominal output. Calibration is accomplished by periodically comparing the hot load with a known temperature load (ambient load) within the instrument. The instrument is then coupled to the Nimbus 5 spacecraft providing a movable platform imparting motion in the non-scan plan of the antenna. This provides the necessary spatial displacement to generate two dimensional radiometric maps. Figure 2-1 depicts the Electronically Scanning Microwave Radiometer mounted aboard the Nimbus E Spacecraft.

The specifications for the radiometer system are provided in Table 2-1.

2.2 APPLICABLE DOCUMENTATION

The following is a list of the documentation for the Electrically Scanning Microwave Radiometer. Not included in this list are monthly progress reports, malfunction reports, screening reports and milestone reports.

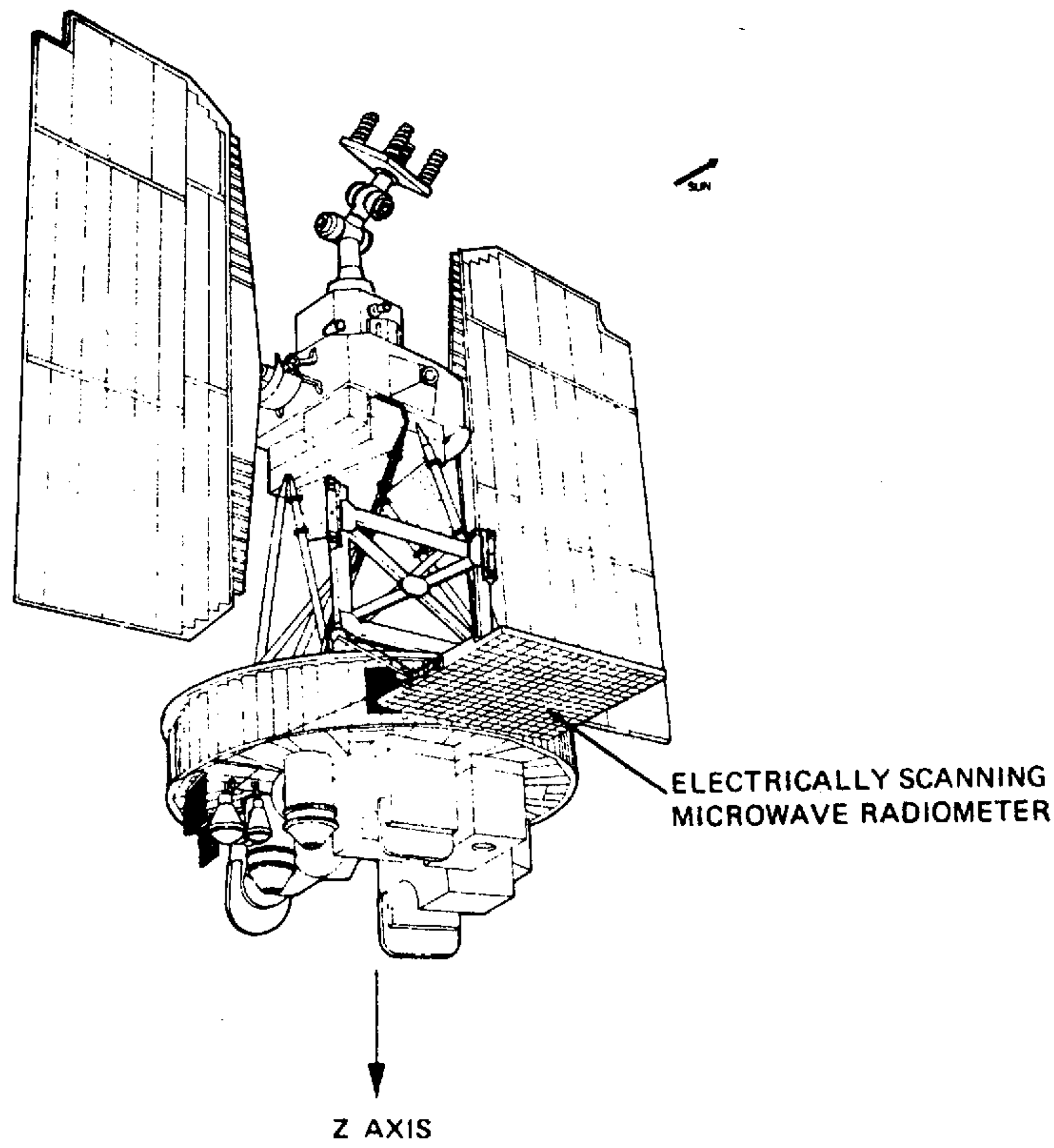


Figure 2-1. Electrically Scanning Microwave Radiometer Mounted Aboard the Nimbus E Spacecraft

Table 2-1

SPECIFICATIONS FOR RADIOMETER SYSTEM

Receiver	Specification
Center Frequency	19.35 GHz
Bandwidth I. F. (nom.)	10-150 MHz
Bandwidth R. F. (nom.)	300 MHz
Mixer Noise Figure	6.0 dB
ΔT_{rms}	1.5° K
Absolute Accuracy	2.0° K
Dynamic Range, Calibration	$50-330^{\circ}$ K
Antenna	
Nadir 3 dB Beamwidth	$< 1.4^{\circ}$
Scan Time	4.0 sec
Loss	< 2.0 dB
Polarization	Linear
Sidelobe Contribution	< 7%
Scan Angle	$\pm 50^{\circ}$
Total Experiment Weight	67 lbs
Experiment Size	36" x 36" x 6"
Total Power Requirement	41.2 watts

The operation of the instrument is completely described in the Operation and Maintenance Manual, MW-PROC-8021.

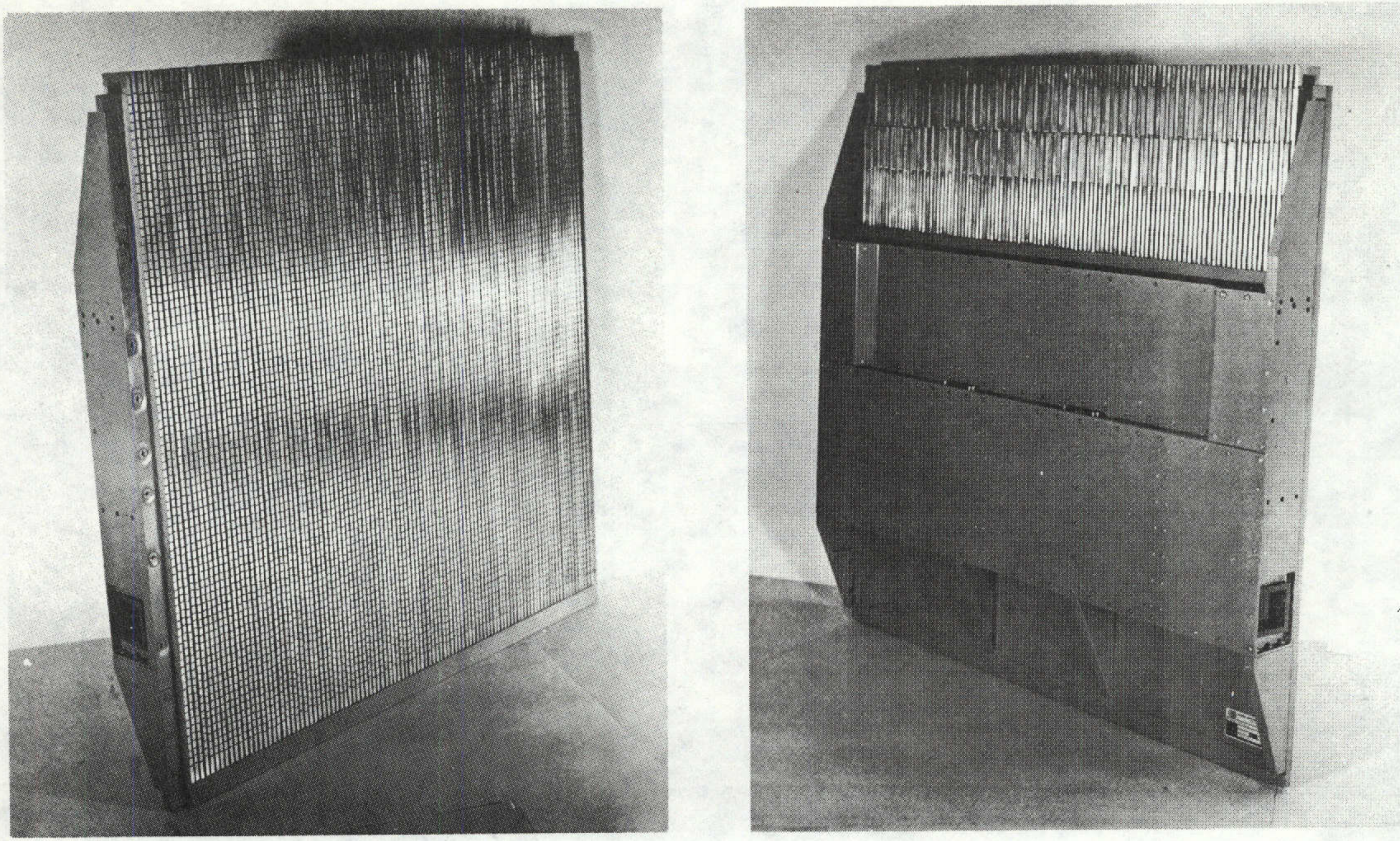
Document No.	Title	Date Submitted
- -	Still Documentary Photography	1-15-73
1740 IM-1	Integration Manual for ESMR Nimbus E, October 1972	7-7-72
	Environmental Test Report ESMR Protoflight Model	7-7-72
	Environmental Test Report ESMR Flight Model	7-7-72
	Calibration Report ESMR Engineering Model	7-7-72
	Calibration Report ESMR Protoflight Model	7-7-72
	Calibration Report ESMR Flight Model	7-7-72
MW-PROC-8021	Operation and Maintenance Manual	5-9-72
	Calibration Report, ESMR Antenna Acceptance Test, Flight Model	5-4-72
SK1488-2001	ESMR Mechanical Interface Drawing	1-21-71
	ESMR List of Bulk and Raw Materials	7-20170
1488 Q-2	Reliability Program Plan	5-12-70
	Inspection Flow Diagram	5-12-70
1488 Q-1	Quality Program Plan	4-29-70
	Microwave Division Quality Control Manual	4-20-70
MW-SP-3001 D	Switch, Ferrite, RF	3-8-72
MW-SP-3003 N/C	Oscillator, Solid State, RF	5-7-70
MW-SP-3020 N/C	Integration Specification	12-1-71
MW-PROC-8012A	Acceptance Test Procedure, Ground Support Equipment Calibration/ Checkout Bench Test Unit No. 2	5-1-71

Document No.	Title	Date Submitted
MW-PROC-8013 N/C	Ground Support Equipment Operation Maintenance and Handling Procedure Calibration/Checkout Bench Test Unit No. 2	5-1-71
MW-PROC-8014A	Shipping and Handling Procedure	12-15-71
MW-PROC-8015A	Acceptance Test Procedure ESMR Antenna	12-11-72
MW-PROC-8016A	Acceptance Test Procedure ESMR Receiver	6-15-71
MW-PROC-8017D	Acceptance Test Procedure ESMR	1-12-72
MW-PROC-8018A	Test Procedure Antenna Loss Measurement	1-17-72
MW-PROC-8019B	Acceptance Test Procedure Ground Support Equipment Electrical Checkout Bench Test Unit No. 1	9-15-71
MW-PROC-8022B	Environmental Test Procedure	11-5-71
MW-PROC-8033 N/C	Test Procedure Liquid Nitrogen Target	1-19-72

2.3 MASS MODEL

The Mass Model constructed under Contract NAS 5-21115 was actually the second Mass Model of ESMR. The first Mass Model was constructed under Contract NAS 5-11633. Structural deficiencies required the construction of the second Mass Model. The first Mass Model is shown in Figure 2-2.

The second Mass Model was completed early in October 1970 and was vibration tested at Ogden Laboratories on October 13, 1970. The vibration test revealed a resonance at 71 Hz, which was not acceptable. The Mass Model was fitted with a stiffener channel which fit over the end of the model near the phase shifters. This aluminum hat-shaped structure later supported the cable guides.



ANTENNA SIDE RECEIVER SIDE

Figure 2-2. Nimbus E Mass Model Number 1

The final vibration test of the model was performed at Ogden Laboratories on November 12, 1970. The results of this test were satisfactory and the Mass Model was shipped to GE/VFSC on November 19, 1970. The second Mass Model is shown in Figure 2-3.

2.4 ENGINEERING MODEL

Fabrication of the Engineering Model of ESMR was begun in April 1970 and completed in February 1971. The environmental testing of the Engineering Model was accomplished during the month of March 1971. The environments included weight, center of gravity, RFI, thermal soak and vibration. The model was susceptable to RFI at 136.5 MHz and was corrected through filtering of the mixer and intermediate frequency amplifier. The unit also failed at +45°C. The failure of the radiometer to operate at +45°C was isolated and found to be caused by a temperature sensitive integrated circuit in the timing and control counter. After replacement of the I.C., thermal tests were repeated without failure.

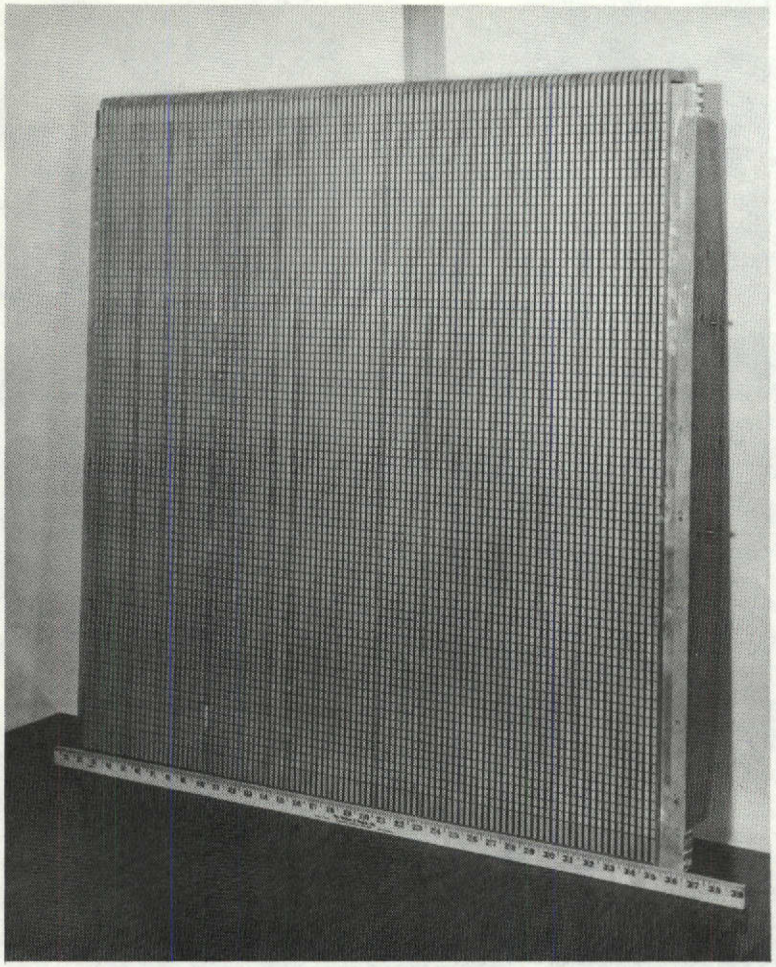
The Engineering Model was crated and shipped to GE/VFSC along with BTE #1 and BTE #2 on the 1st of May 1971. At GE, the hardware was uncrated and given a modified acceptance test by Aerojet-General, Microwave Division personnel. The ESMR measured radiometric temperatures to an absolute accuracy of 0.5°K with a standard temperature deviation (ΔT_{rms}) of between 1.4 and 1.6°K.

The scan driver output voltages were monitored through connectors J4 and J5 on the ESMR. These voltages were recorded on a ten channel Brush recorder for future analysis by Microwave Division personnel.

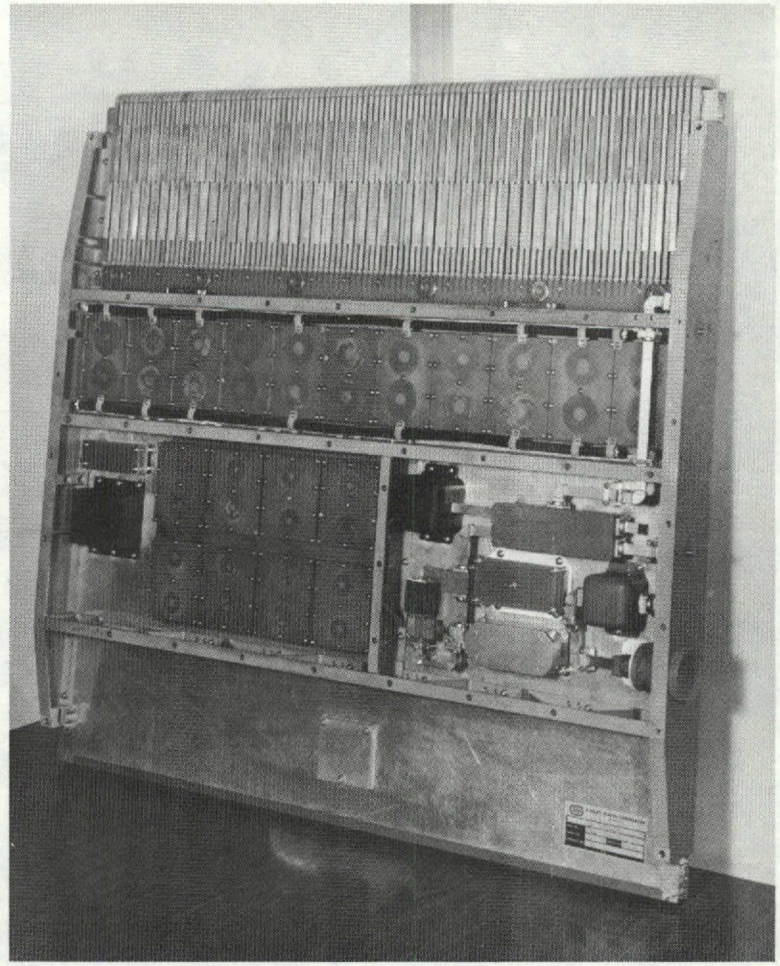
The ESMR was then integrated into the BIT (Bench Integration Test) facility for a compatibility test. For the results of this test, refer to the completed integrated test procedure (ITP 1420-NE-004) at GE/VFSC.

During BIT testing, the following discrepancies were noted:

- The grounds for chassis, signal and power were tied together in ESMR. The fix involved the separation and isolation of the grounds.



ANTENNA SIDE



RECEIVER SIDE

Figure 2-3. Nimbus E Mass Model Number 2

- No digital B information on J1-28 (output frame identification). The difficulty was traced to a miswire in module A-7 and was corrected.

- SAGC readout inoperative. Difficulty traced to broken wire in module A-7 which occurred during repair of the above.

- Digital A output not synchronized to VIP (Versatile Information Processor) frame. Difficulty traced to an incorrect polarity of the MFP (Major Frame Pulse) input. This was corrected by reversing the MFP leads in the VIP. Later analysis has shown that the negative going MFP should have been presented at J1-14 rather than J1-31.

- Digital A out of synchronization with VIP by one word (50 ms). The FID (Frame Identification) appeared on the first word rather than the last. This was corrected by a change in the TCC (Timing and Control Counter).

- Spurious operation of VIP synchronization and occasional word errors. This was traced to a malfunctioning flip-flop in Module A-7. The problem was corrected.

- High current pulses on the -24.5 VDC input lines during turn-on.

After the conclusion of BIT testing at GE/VFSC, the ESMR and associated BTE were sent to NASA/GSFC for magnetic moment testing. The test revealed residual magnetic moments which were probably caused by the magnetic field of the isolators in the RF section. The test concluded, however, that these were inconsequential, and the system passed the test.

The equipment was then returned to GE/VFSC. The ESMR was then crated and shipped back to AGC/MD with the two Bench Test Equipments remaining at GE/VFSC.

During the system inspection and test at AGC/MD it was found that all but one of the direct reading telemetry circuits were inoperative. Upon investigation, all the failures were traced to the transistors in the double Darlington circuits.

A solution to the susceptibility of the ESMR to radiation at 136.5 MHz was incorporated in the radiometer. RFI filters were added to all leads going to the mixer-IF assembly as shown in Figure 2-4.

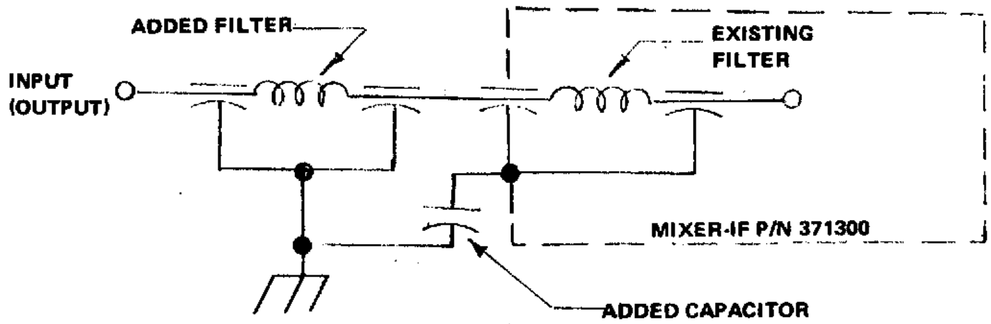


Figure 2-4. RFI Susceptibility Corrections

The new filters were installed in the bulkhead housing of the radiometer section using the bulkhead as chassis ground. The 13.6 MHz applied via a tuned dipole at 1 meter from the ESMR antenna. The signal was pulse modulated at a 4 KHz rate with a 50% duty cycle at an average power level of 1/2 watt. Change in the BIDEC count was minimal. An average count (78 samples) of 836.4 and 836.5 was recorded with and without RFI respectively. There was no increase in average deviation (ΔT) with the application of RFI.

The ESMR Engineering Model tests were completed at AGC/MD including the measurement of current transients on the -24.5 VDC input and the chart recordings of the phase shifter coil voltages for beam positions 5 through 103 in the scan mode. The current transient for the 'RADIOMETER ON' position was 4.0 amperes. This was 2.0 amperes over the requirement of X-450-68-415. No discrepancies were noted for the beam position voltages.

The Engineering Model was taken to Table Mountain for measurement of the insertion loss of the antenna.

The ESMR Engineering Model was sent to the General Electric Valley Forge Space Center on Monday, July 26, 1971. The unit was uncrated and inspected visually for any sign of shipping damage, both by G.E. and AGC/MD. No sign of damage was found and the unit was moved to the BIT (Bench Integration Test) area for acceptance testing. The unit was acceptance-tested the following results as shown in Figure 2-5.

FUNCTION	RUN				
Analog	1	2	3	4	5
0	3.91	3.92	3.91	3.88	3.91
1	1.32	1.33	1.28	1.22	1.23
2	1.51	1.50	1.51	1.48	1.52
3	1.54	1.55	1.55	1.54	1.56
4	1.54	1.55	1.55	1.52	1.55
5	1.42	1.43	1.42	1.40	1.42
6	1.55	1.55	1.56	1.52	1.56
7	1.10	1.10	1.12	1.10	1.15
8	4.08	4.11	4.13	4.12	4.15
9	4.37	4.42	4.44	4.46	4.48
10	4.53	4.58	4.60	4.61	4.65
11	4.60	4.65	4.67	4.67	4.70
12	4.33	4.38	4.40	4.40	4.44
13	4.25	4.30	4.32	4.30	4.35
14	4.47	4.53	4.54	4.55	4.58
15	1.21	1.21	1.20	1.18	1.21
MUX					
1	605	602	599	596	594
2	613	609	606	601	600
3	608	606	603	603	603
4	612	607	608	603	602
5	515	515	513	516	515
6	447	447	447	447	447
7	664	664	664	664	664
8	000	000	000	000	000
Cold Ref. Ave.	947	961	959	958	922
Hot Ref. Ave.	150	152	150	150	149
Variable Load	99.7°K	149.9°K	200.0°K	249.7°K	300.0°K
Variable Window	291.0°K	292.0°K	293.2°K	295.4°K	296.1°K
Sky Load	40.09°K	40.07°K	40.07°K	40.03°K	40.02°K
Sky Window	290.9°K	290.9°K	290.9°K	90.7°K	290.7°K
$\overline{C}$ (78 Sample)	734	599	448	299	147
ΔCrms	5.21	5.51	5.79	4.86	5.78

Figure 2-5. Data Record - July 26, 1971

After acceptance testing, the ESMR was integrated into the BIT board for testing. The ESMR was tested functionally including the recording of current transients and scan driver voltages. The only discrepancies noted were a 4.4 ampere current transient on the power line during radiometer turn-on and a voltage fluctuation in the analog telemeter outputs for linear array temperatures AA and CC.

An 'RFI soak test' was performed by using a ferrite rod antenna which was placed directly on the ESMR in six locations. The ESMR proved to be susceptible to RFI at 136.5 MHz. It was agreed that the test was extremely harsh and not really indicative of actual conditions.

After the conclusion of BIT testing, the ESMR analog telemetry outputs were further studied to determine the cause of variation. A brush recording of the outputs revealed the change in voltage to be abrupt and between 5 and 10% change. Further analysis with a scope revealed a waveform of approximately 0.25 volts, peak to peak, and approximately a square wave in shape with rounded corners.

The data recorded at GE/VFSC on July 26, 1971 were further analyzed at AGC/MD with the results shown in Figure 2-6.

The Engineering Model was once again returned to AGC/MD. It was inspected and found that no damage was incurred during shipping. Anomalies on the analog temperature readouts experienced at GE were investigated. Analog voltages were monitored on a strip chart recorder for five hours. No anomalies occurred. An analytical study was initiated to determine if the fluctuations experienced at GE could be caused by the ESMR.

A test was conducted to simulate the temperature readout anomalies experienced at GE/VSFC. Each of the eight outputs of the temperature readout circuits was passed through a "break-out" box and recorded on a strip chart recorder for an extended period of time. The break-out box was similar to that used at GE/VFSC when the anomalies in the readout circuits were witnessed. The strip chart records were thoroughly analyzed. An anomaly of the type experienced at GE/VFSC occurred with the circuit associated with the linear array "A" temperature thermistor. In order to

Function	Run				
	1	2	3	4	5
Calculated Cold Reference Temp. (°K)	103.51°	103.49°	103.49°	103.49°	103.48°
Calculated Variable Load Temp. (°K)	153.22°	190.19°	226.80°	263.23°	300.02°
Calculated Ambient Reference Temp. (°K)	298.89°	299.27°	299.20°	299.62°	299.62°
Calculated Hot Load (Dicke) Temp. (°K)	334.3°	334.29°	334.39°	334.27°	334.29°
Gain (Counts/Deg.)	4.102	4.164	4.155	4.149	4.162
ΔT_{rms} (°K)	1.3°	1.3°	1.4°	1.2°	1.4°
Ambient Load Abs. Accuracy (°K)	-1.22°	-1.56°	-0.87°	-1.64°	-0.66°
Antenna Port Abs. Accuracy (°K)	+2.06°	0.04°	-0.28°	-1.16°	-1.06°

Figure 2-6. Analysis of Data Recorded - July 26, 1971

return the ESMR to GE/VFSC in an expeditious manner, the two transistors (Q3 and Q4) of this readout circuit were replaced. The two old transistors were put into another readout circuit for additional testing.

The ferrite switch thermistor wiring was changed from analog channel "0" to digital multiplex channel 3 and the waveguide thermistor wiring was changed from the multiplex channel 3 to analog channel "0". A change in the AGC CLEAR command circuitry was also made. When the AGC CLEAR command is executed, the SAGC will adjust the stepped attenuator to 3/8 of the maximum attenuation value rather than to the maximum attenuation value. This SAGC change causes the AGC CLEAR to read out 399 on the digital output instead of 015 when commanded.

The ESMR Engineering Model was sent to General Electric, Valley Forge Space Center on January 4, 1972.

The transistors removed from the faulty double Darlington thermistor readout circuits were installed in a similar circuit in the laboratory. This circuit was tested for an extended period of time. The previously experienced anomalies could not be repeated.

The Engineering Model was returned to AGC/MD from GE/VFSC with a report that there was no analog 6 or digital A output. The unit arrived February 21 and was examined. A broken wire was found in the analog 6 circuitry which caused the no-output malfunction. A broken wire at the input and a broken wire at the output of the switch driver was also found. This caused the no-output condition for digital A. The ESMR was checked and found to be operating normally. It was returned to GE/VFSC on February 22.

No further incidences occurred on the model and it continued through the remaining tests at GE/VFSC and was then placed in storage.

Photographs of the Engineering Model are shown in Figures 2-7 and 2-8.

A post vibration interface dimensional inspection yielded satisfactory measurements and the unit was transferred to TRW for thermal testing.

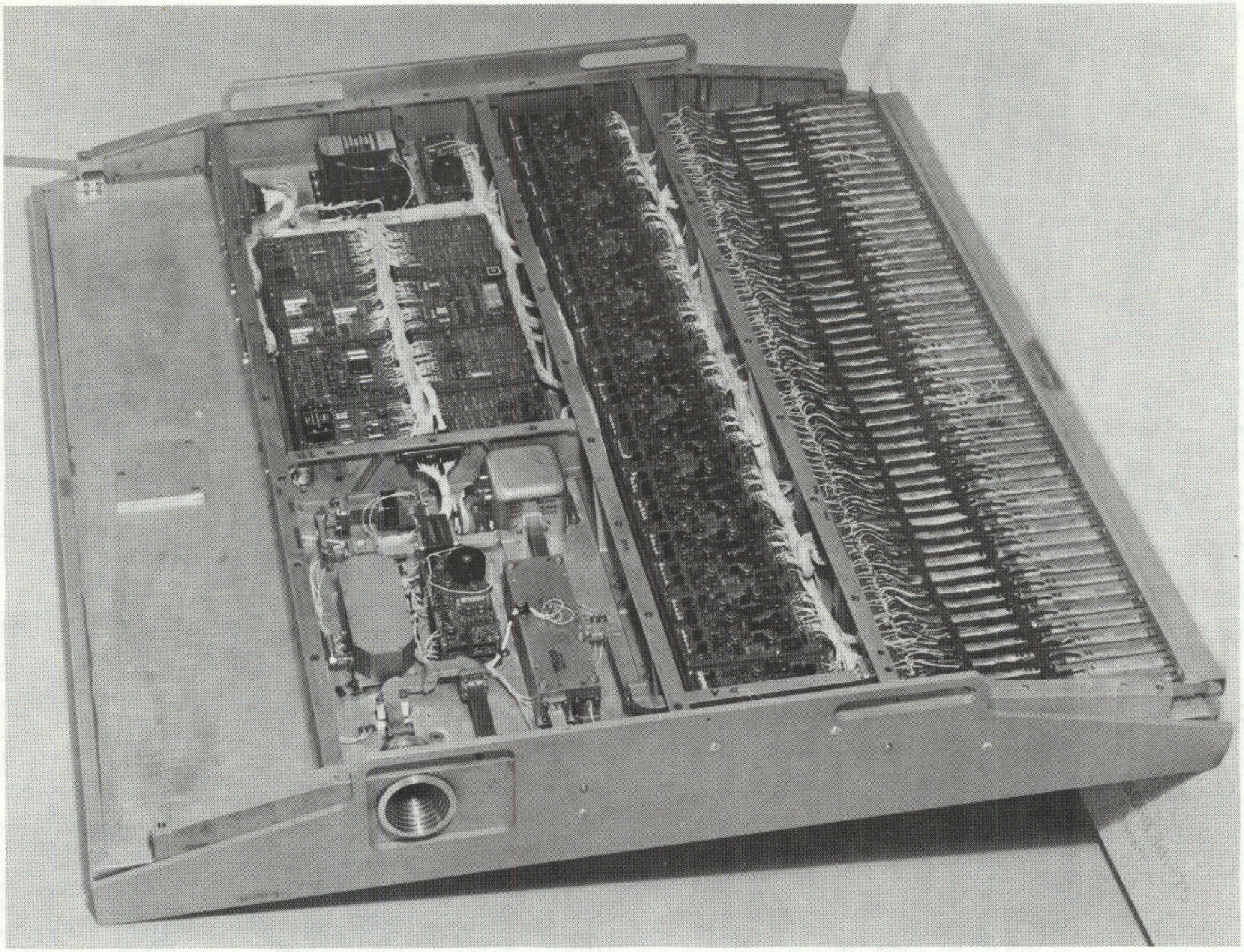


Figure 2-7. ESMR Engineering Model - Component Side

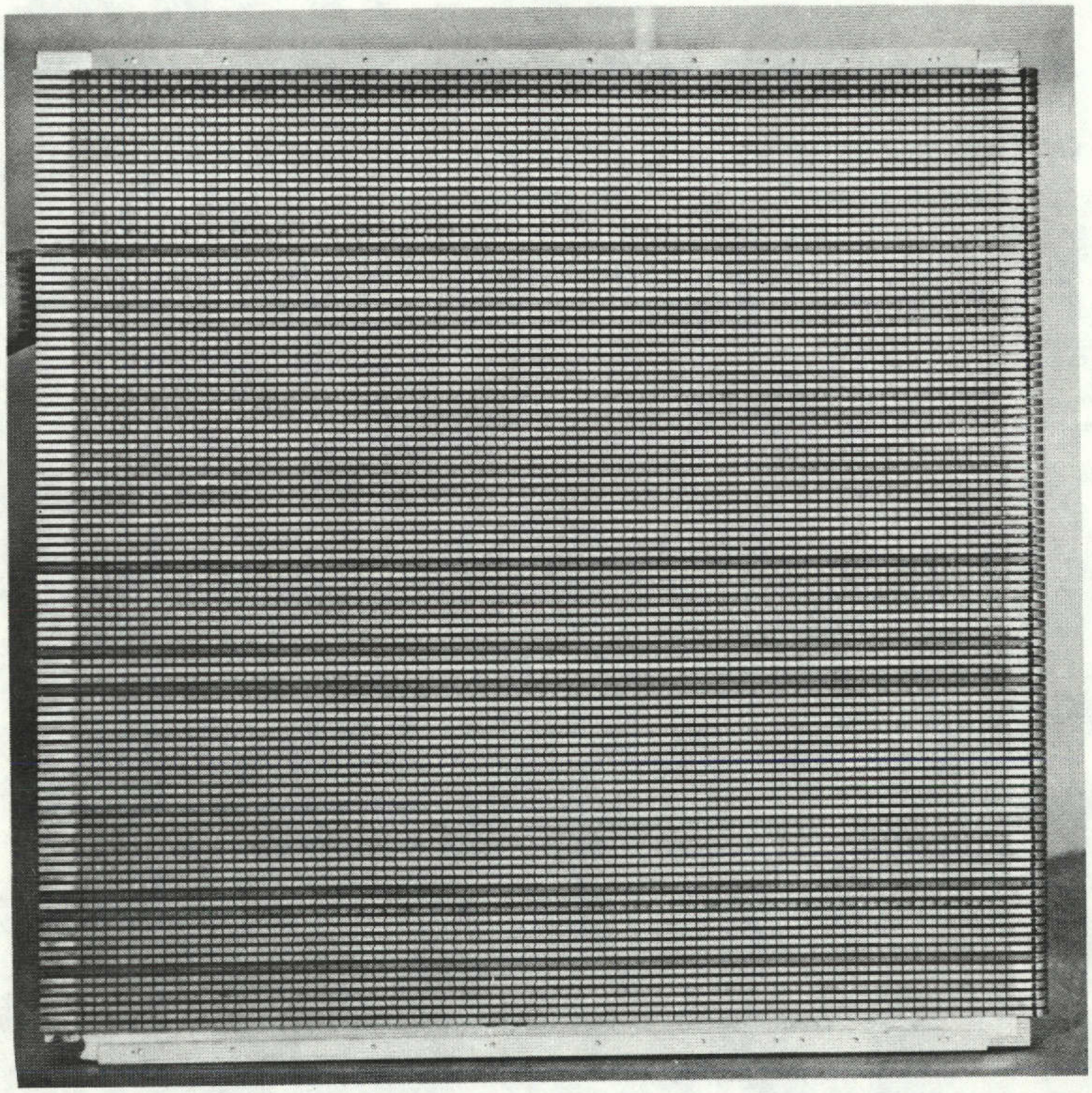


Figure 2-8. Electrically Scanning Microwave Radiometer - Antenna Side

2.5 PROTOFLIGHT MODEL

Fabrication of the Protoflight Model was begun in October 1970 and completed in November 1971. After completion a Systems Acceptance Test (MW-PROC-8012C) was performed.

After successful completion of the Systems Acceptance Test (MW-PROC-8017C) and the RFI portion of the environmental test (MW-PROC-8022B) at AGC/MD, the protoflight unit was transferred to Ogden Labs for weight and center of gravity measurements and vibration test. During the vibration pre-test there was no data output. A faulty pin in a connector was suspected (however, the problem was traced to a DC to DC converter problem described later). The connector was repaired, the pretest was successfully completed, and the vibration test begun.

During vibration in the thrust axis a wire on pin J1-23 broke and the command buttons failed. This was corrected and the thrust axis was successfully repeated. A low output during vibration in the transverse axis was traced to broken IC leads in the mixer/IF.

During the transverse axis random test, a lack of radiometer output was traced to broken coils in the IF amplifier. This was corrected, the test was restarted, and a second failure occurred. This failure was caused by broken capacitor leads in the IF amplifier. The capacitors were a glass type, could not be epoxyed, and had been held in place with conformal coating material. It was determined that the coating compound used during a rework cycle had not been completely cured prior to the unit's being put back into test. Upon correcting the problem, the test was rerun and successfully completed.

A post vibration interface dimensional inspection yielded satisfactory measurements and the unit was transferred to TRW for thermal testing.

A functional evaluation was performed at TRW prior to the start of thermal balance measurements. A broken wire on pin 16 of J1 was discovered during this test and was corrected. The thermal balance measurements were successfully completed and the adequacy of the thermal design substantiated. The results of this thermal balance test are included herein as Appendix A.

During the thermal vacuum test several computer errors during the first 12-hour high temperature exposure forced cancellation and a restart of the test.

During the first low temperature exposure the multiplexed outputs were in an improper sequence. The system was returned to ambient. A SM54L72 flip-flop I.C. in the A/D converter was determined to have failed when cold and was replaced. It was also noted during a subsequent ambient functional evaluation that the MUX parameters were occasionally out of sync. This problem was traced to a solder chip and a pinched wire on the Analog-to-Digital Converter "A" board. These two conditions occurred during the replacement of the SM54L72 I.C.

The ESMR system was placed in a thermal chamber and thermally cycled to detect any additional thermal problems. It was noted that at high temperatures the Hot Load MUX count was high. This problem was traced to a broken wire on Pin 5 of P6.

At cold temperatures the lack of a radiometer output was traced to a faulure of the SHX-424 DC-DC converter to turn on reliably. An analysis of the circuit indicated that insufficient bias current was supplied to the switching transistors Q5 and Q6. In order for the converter to start reliably one of the two transistors, i.e., Q5 or Q6, must supply enough current to saturate the transformer. At low temperatures the reduced permeability of the transformer core material and slower switching time of the output rectifiers required a larger amount of transistor collector current to cause core saturation. The base bias resistor was changed so as to provide sufficient base drive current to insure proper turn-on.

Thermal vacuum tests were commenced on December 2, 1971. During the cold temperature cycle it was noted that the multiplex parameters were intermittently out of sync. The test was continued while an investigation of the cause of the sync problem was being made. During the hot temperature cycle of the test the multiplex parameters continued to lose sync intermittently. It was determined that this condition occurred due to false major frame identification pulses. The ESMR was returned to ambient temperature for further evaluation. The problem continued to occur intermittently.

This problem was traced to the thermocouple attached to a ferrite switch drive transistor and to the thermocouples attached to the ESMR frame. These thermocouples were a part of the test equipment used by TRW to control the thermal vacuum chamber temperature during test. The thermocouples were periodically sampled during the course of the test. When sampled, a large noise spike was generated through the thermocouple wiring which was coupled into the major frame identification pulse line from the Bench Test Unit. Noise spikes on the major frame identification pulse line caused the multiplex readings to be out of sync. For the duration of the test the thermocouples were sampled only during times when ESMR test data were not being taken. The ESMR system thermistors were also utilized for chamber temperature monitor and control.

The test was restarted on December 8. It was noted that the stepped AGC count skipped. High ambient RFI was suspected to be the cause of this malfunction. A capacitor was added between the stepped AGC clock drive line and ground to eliminate this problem.

The test was restarted on December 11 and continued without difficulty until the thermal vacuum chamber lost vacuum during the 48-hour high temperature test. The chamber was repaired and the thermal vacuum tests were completed on December 19 without further incident.

Bench calibration and coil voltage tests were conducted at the MD/AGC facilities and completed on December 28. Preparations were made to move the ESMR to the Table Mountain facilities for antenna loss measurements (MW-PROC-8018) but had to be postponed due to bad weather and for roads to be cleared of snow. The ESMR was shipped to Table Mountain on December 31. This test was completed and the ESMR was returned to AGC/MD on January 5, 1972.

The ESMR was taken to the antenna range and digital pattern measurements were made. Upon examination of data during these measurements, it was noticed that there was an anomaly in the phase shifter coil current waveforms. The ESMR was returned to the Clean Room on January 11. The problem was traced to a broken wire in the Increment Adder.

After rework, the coil current waveforms were proper. Upon analysis of the previous coil current waveforms it was noticed that this condition existed prior to initiation of environmental test. The effect of the broken wire was a 3% error in the positioning of the antenna beam.

On January 13, the ESMR was returned to the antenna range for pattern measurements. Checkout of the measuring equipment with the ESMR continued. Measurements commenced on January 16. Patterns were measured for the 78 beam positions, the Fail Safe position, and the no power condition. The patterns were acceptable.

To insure that the loss measurements made prior to the Increment Adder rework were still valid, the ESMR was returned to the Table Mountain Facilities and new measurements were made. Antenna losses were essentially unchanged.

While at Table Mountain a problem developed in the hot lead. The trouble was traced to two broken wires in connector J6. These wires were determined to have been broken during the antenna pattern measurements of January 16 and were repaired.

The ESMR was returned to AGC/MD on January 18 and the Bench Calibration Test (MW-PROC-8017) was successfully conducted on January 19. The covers were installed and Functional Test (MW-PROC-8033) was successfully conducted on January 20.

A final vibration test (MW-PROC-8034) was performed at Ogden Laboratories. This was followed by a repeat of the functional test at AGC/MD. A GE compatibility test was conducted on January 21. All tests were accomplished successfully.

The ESMR was packed and shipped to GE/VFSC on January 24, 1972. AGC/MD personnel accompanied the system to GE. Upon arrival at the GE/GSFC facilities the unit was uncrated and inspected visually for any sign of shipping damage. No sign of damage was found. The functional test (MW-PROC-8033) was conducted by AGC/MD personnel aided by GE/VFSC personnel. The ESMR functioned properly.

When the Protoflight Model was placed on the deployment mechanism at G.E. a slight interference occurred in the stowed position. The foam insulation on ESMR was slightly dimpled by screw heads on the deployment mechanism. It was also noted that the foam was too close (but not touching) to the mechanism near the interface bracket area. The areas that were interfering were modified when the unit was returned to AGC/MD and the drawings were revised to incorporate the change.

The Protoflight Model was integrated into the BIT (Bench Integration Test) facility at G.E. During the integration test, it was found that the model had a timing error in the digital output. A one word error occurred in every subframe (4 seconds) causing word 1 in the VIP (Versatile Information Processor) to read word 80 from ESMR. The Protoflight Model was then shipped back to AGC/MD at El Monte for failure analysis.

The timing error was caused by the failure of the Microwave Division to retrofit the Timing and Control Counter to an existing B revision to the drawing. The revision was made to the unit eliminating the timing error.

The Protoflight Model was then reassembled and sent to Ogden Laboratories for a random vibration test to MW-PROC-8034. The model was then shipped back to GE/VFSC where it successfully passed the requirements of integration testing on the BIT facility. After BIT testing, the Protoflight Model was placed in bonded stock at GE/VFSC. A photograph of the Protoflight Model is shown in Figure 2-9.

2.6 FLIGHT MODEL

Fabrication of the Flight Model was begun in February 1971 and completed February 1, 1972. The ESMR was taken to the Table Mountain facility on February 3 and the Antenna Loss Measurement Test (MW-PROC-8018) was conducted. It was noted during the test that under warm ambient conditions the stepped automatic gain control (SAGC) setting, when cleared, was below the normal inhibit value of 399.

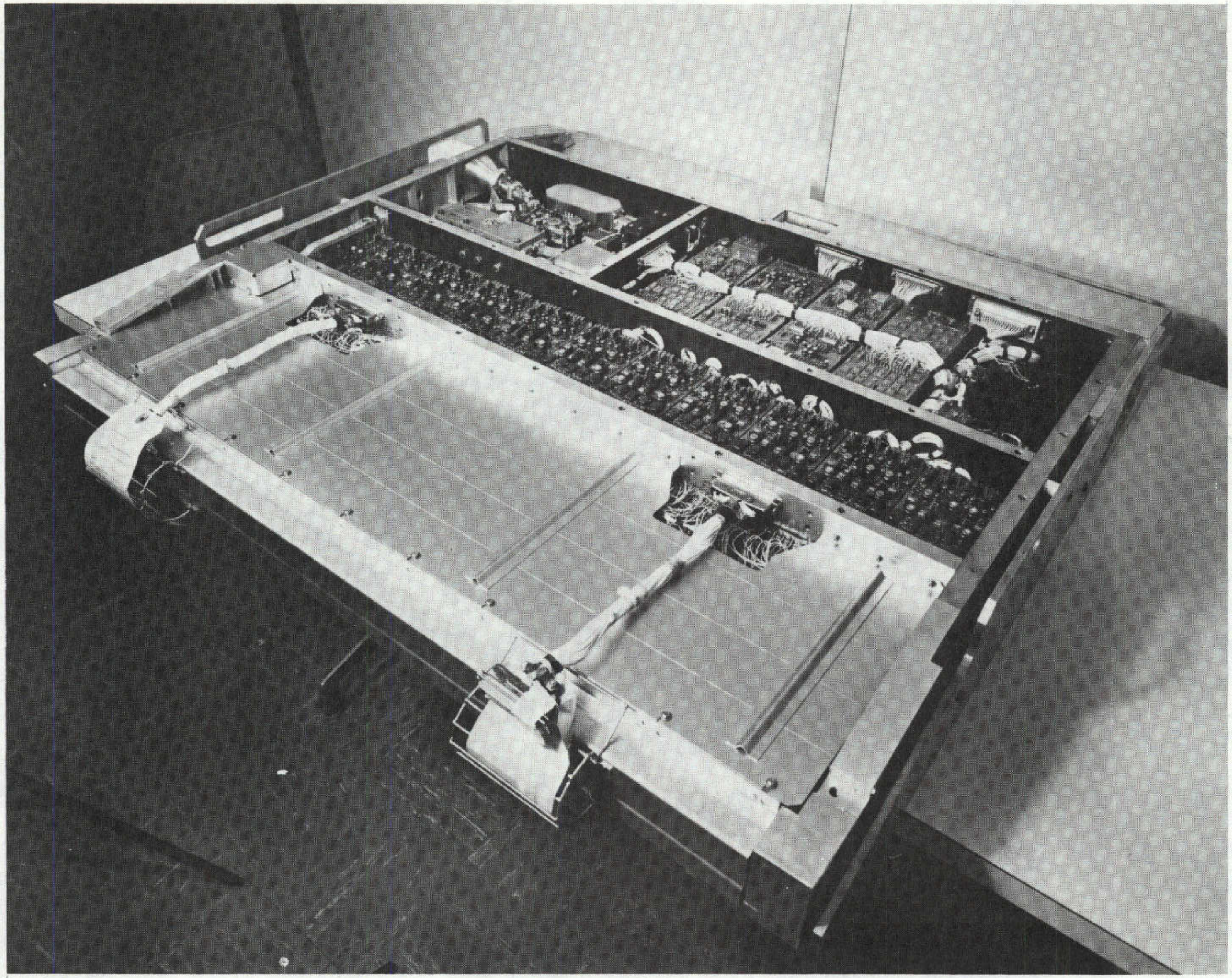


Figure 2-9. ESMR Protoflight Model

Upon completion of the loss measurement test on February 4, the unit was returned to AGC/MD facilities and engineering evaluation tests were made concerning the SAGC. The gain of the video amplifier was reduced to allow a nominal setting of 479 when the SAGC was cleared.

The Bench Calibration Test (MW-PROC-8017) was conducted prior to initiating the Environmental Test (MW-PROC-8022). The center of gravity was determined on February 6 and the unit was transported to TRW test facilities the next day, and weighed on February 8. The ESMR weight was 31.00 kg (68.35 lb).

Vibration tests were initiated the same day. During the thrust axis and Y axis tests, step gain changes were noted. The ESMR was returned to AGC/MD for evaluation of this symptom. The problem was traced to the Gunn oscillator (S/N 116). The faulty oscillator was removed and sent to the vendor for repair. Repairs consisted of optimization of the units internal impedance and replacement of the diode. The oscillator was returned to AGC/MD and installed on February 9. The ESMR was returned to TRW on February 10 for continuation of vibration test. While calibration of the vibration table was being performed with the mass model, excessive cross-axis vibration levels were experienced. It was decided that the Flight Model should go into the thermal vacuum test while the table was being repaired and calibrated. A post vibration mechanical inspection per MW-PROC-8022 and the Bench Calibration Test was conducted on the Flight Model on February 10. Thermal vacuum testing (MW-PROC-8022) commenced the next day. The tests were completed on February 18 and the ESMR was installed on the vibration fixture the same day. Remaining vibration tests were completed without incident. The ESMR was returned to AGC/MD where interface dimension and post vibration mechanical inspections were performed on February 21.

The Bench Calibration Test was performed prior to shipping the ESMR to Table Mountain for post vibration antenna insertion loss tests. The ESMR was returned to AGC/MD on February 28.

The modification on the foam insulation as described for the Prototype was also made on the Flight Model. A check on the timing revealed the same timing slip as seen on the Protoflight and this too was corrected.

The Flight Model was tested to the final Bench Calibration Test (MW-PROC-8017), Functional Test (MW-PROC-8033) and then a Final Vibration Test (MW-PROC-8034). During the Functional Test after vibration, it was noted that analog #2 was not present. The cover was removed and the fault isolated to a broken wire (GSFC MRD02271). The wire was repaired and the Flight unit revibrated to MW-PROC-8034. After vibration another Functional Test (MW-PROC-8033) was performed.

In addition to the above required testing, the Flight Model was tested for coil currents, current transients, continuity measurements, output voltages and susceptability at 136.5 MHz (2 watts CW). All tests were satisfactory.

The Flight Model was then shipped to GE/VFSC (March 27, 1972) after which it successfully passed both BAT (Bench Acceptance Test) and BIT.

During the integration of the Flight Model to Nimbus E, field support was requested at G.E. by the Nimbus Project Office to determine the cause and possible cure for an RF interference problem with the Nimbus E Spacecraft. The ESMR was detecting a strong signal from the sensory ring while ESMR was in the stowed position. It caused saturation in several of the beam positions and erratic behavior in all others. The interference only occurred when any of the three S-band telemeter transmitters were turned on.

Several tests were performed to determine if ESMR is susceptible to the beacon frequencies of 1702.5, 1707.5 and 2208.5 MHz. These tests concluded that ESMR was not susceptible to these frequencies, but rather that the interfering source was within the bandpass of ESMR. Further testing revealed that the three S-band telemeter transmitters were emitting energy from four holes in each transmitter case which were drilled to prevent transmitter multipacking*. The four holes in one of the transmitters (S-band "A") were

* A term used to describe an unwanted condition which causes frequency instability in tuned cavities. It results from a combination of cavity size and atmospheric pressure.

covered with a copper tape to ascertain that the radiation was emanating from the holes. The test was conclusive in that the interference was no longer present when S-band "A" transmitter was turned on and off.

Large holes, 1/4" in diameter, were drilled by the manufacturer (Teledyne) in order to guarantee proper venting without need for vacuum analysis. The hole appeared to have a depth of about 1/8". A 1/4" hole appears to be beyond cutoff since according to Moreno's book on transmission lines, the formula for cutoff in the dominant TE_{11} mode is:

$$\lambda_c = \frac{2\pi a}{1.841}$$

where a is the radius of the circular guide. This calculates out to a frequency of 27.66 GHz for a 1/4" hole. Still, according to Moreno, the attenuation will be:

$$\alpha = 8.69 \sqrt{\left(\frac{1.841}{a}\right)^2 - \left(\frac{2\pi}{\lambda}\right)^2} \text{ dB/unit length.}$$

Calculating this out for a frequency of 19.35 GHz reveals the hole to have an attenuation of 91.47 dB per inch or a total of 11.43 dB per hole. Since there are four holes, it can be assumed that whatever is on the inside gets attenuated by only 5.43 dB before it gets to the outside world and ESMR.

The radio frequency interference problem was resolved by shielding the holes in the spacecraft telemetry transmitters. The ESMR proved not susceptible after the fix was installed.

The ESMR Flight Model continued through the spacecraft integration tests with no failure until thermal vacuum testing. During a retest phase of thermal vacuum, the Dicke load thermistor readout circuit showed an intermittent condition. The circuit involved places the physical temperature of the Dicke load in the digitial A stream to VIP on multiplex channel 5. The anomaly caused a shift of approximately 100 counts (out of 1023) on an intermittent basis. Through further investigation it was determined that the logical cause of the disturbance is an operational amplifier (AR7, an M501B) in schematic 1371284. Since the circuit involved is a multi-redundant circuit, the decision not to repair was made.

On October 20, 1972 the ESMR radiometric output indicated a random increase in temperature. The random temperature changes lasted about 15 seconds starting approximately at 2239 spacecraft time. The data records showed the anomaly to be typical of an external RFI source, probably in the I.F. band of ESMR. The ESMR was in the anechoic chamber at GE with ESMR deployed and in full operation.

A second and third occurrence of random temperature increases occurred at 0538 and 0610, spacecraft time, on October 23, 1972. The appearance of the data was essentially the same as the occurrence on October 20, but much shorter in duration. The spacecraft was outside the anechoic chamber with ESMR stowed for this test. Aerojet ElectroSystems was requested to send field service support in order to isolate the problem.

While at GE/VFSC every effort was made by Aerojet and GE to isolate the problem. Several sources of external RFI possibilities were uncovered but no conclusions could be reached. The spacecraft was vibrated in the thrust (yaw) axis at full sinusoidal qualification inputs. A ring confidence test held after sine vibration on October 28 revealed no further anomalies. Field Service support was discontinued at this time with the assurance that GE would further investigate the anomaly after the spacecraft had finished vibration testing.

The Flight Model continued through integration tests at GE/VFSC. The Nimbus E Spacecraft was shipped to the Western Test Range at Vandenberg, California, on November 25, 1972, and launched December 11, 1972, at 2357 hours. A photograph of the Flight Model is shown in Figure 2-10.

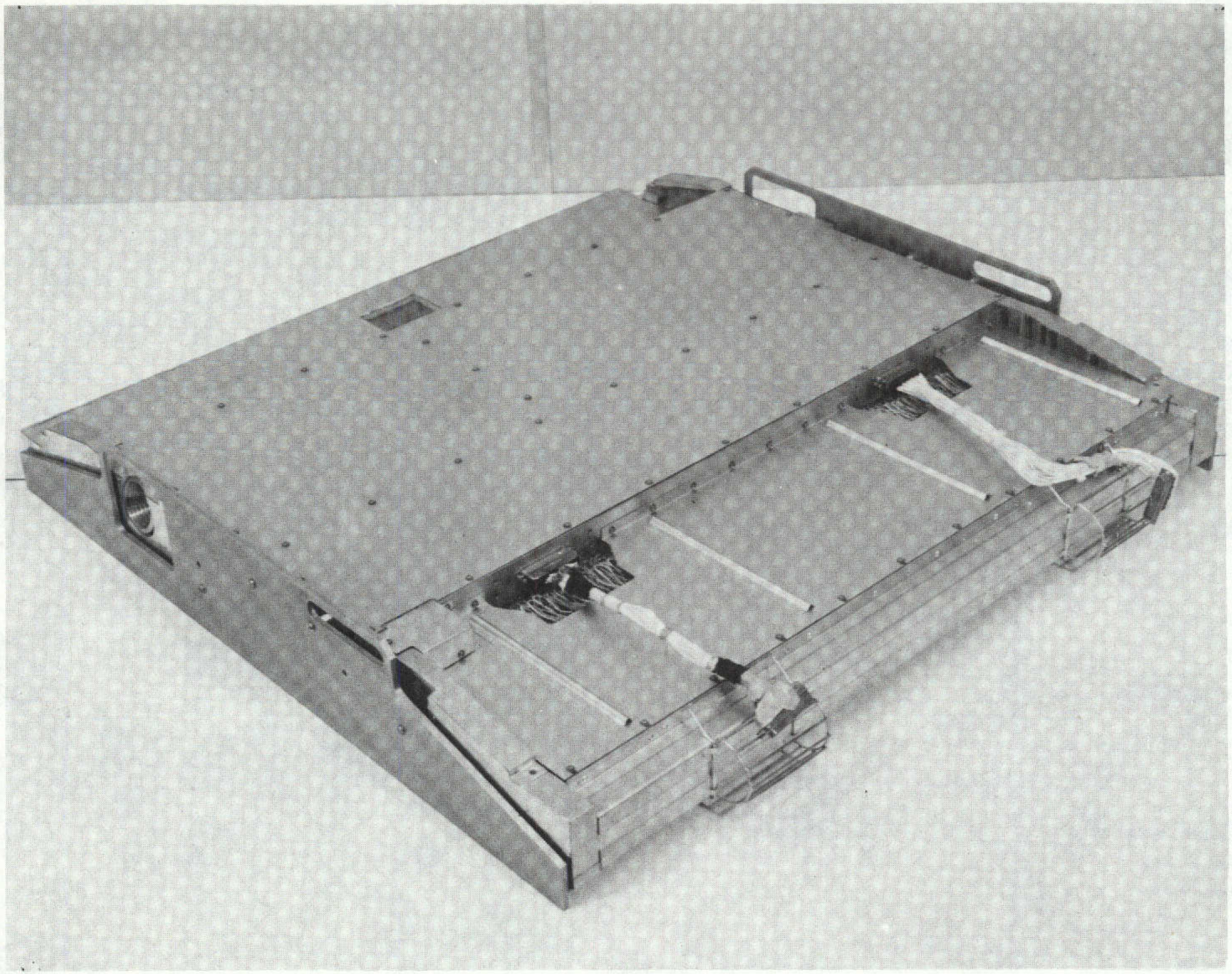


Figure 2-10. ESMR Flight Model

Section 3

BENCH TEST EQUIPMENT

3.1 GENERAL

The Bench Test Equipment for the ESMR consists of two basic units. One unit is the spacecraft telemetry simulation unit referred to herein as BTE #1 and the other is the variable cold load source, BTE #2. These two units provide the means to accurately calibrate the radiometer under conditions equivalent to actual spacecraft operation. Pertinent features of BTE #1 are as follows.

The Telemetry Simulating Unit provides the ESMR, power, clock signals, digital A timing signals and command relay drive signals. The unit will also accept and display from ESMR, digital A (primary data), digital B and analog data.

Power to ESMR is supplied by means of a regulated power supply with front panel meters indicating supply voltage and radiometer supply current. Primary power is nominally 24.5 volts. Output voltage of the primary power supply may be varied (continuously) by means of a front panel potentiometer from 0.0 to 40 volts.

The clock signals supplied to ESMR are 2.4 KHz square wave and a major frame pulse, 250 μsec wide occurring once every 16 seconds. Amplitude of these clock signals will be equivalent to the amplitude of the spacecraft clock signals (five volts nominally).

Digital A timing signals "A_1", "B_1" and "C_1" are supplied to ESMR. The "B_1" transfer pulse and ten "C_1 shift pulses occur every 2.5 ms. The "A_1" enable pulse, enabling the ESMR Digital A readout, occurs once every 25 ms. Amplitude of these signals will also be equivalent to spacecraft Digital A amplitudes (five volts nominally).

Command relay drive signals are two simultaneous 24 volts amplitude pulses applied to the proper MA and MB lines. The pulses are 40 ms in duration initiated by front panel push-button switches.

ESMR Digital A output is displayed by means of a BIDEC readout and a digital printer. A five-position rotary switch is used to select the Digital A data to be displayed and printed. Position No. 1 will display and print one of the 78 beam positions per scan (subframe). The particular beam position selected (per scan) is determined by a two decade thumbwheel switch operating in conjunction with position No. 1 of the rotary selector switch. Position No. 2 of the switch will display and print each Hot Reference output. Position No. 3 will display and print each Cold Reference output. Position 4 displays and prints continuously all ESMR Digital A outputs (40 outputs per second). Position No. 5 will display and print one of the eight multiplex parameters of the ESMR frame (80th output of each subframe). The particular multiplex parameter displayed is selected by means of a one decade thumbwheel switch operating in conjunction with Position No. 4 of the rotary selector switch.

Digital B outputs are displayed by means of lamps within the push-button switches which activate the ESMR command relays.

Analog telemetry outputs are selected by means of a 14-position rotary switch and displayed by a digital voltmeter.

The Telemetry Simulating Bench Test Unit is housed in a standard 19-inch relay rack and is as shown in Figure 3-1.

The variable cold load source provides variable temperature microwave terminations to the ESMR by means of two closed cycle cryogenic coolers which use helium as the coolant. One of these coolers is used to provide a simulated space temperature at the cold horn input into the radiometer while the other provides the means to calibrate the radiometer input. The loads are variable from approximately $40^{\circ}K$ to $350^{\circ}K$. The load temperature is displayed on the face of the test equipment on the DORIC readout unit.

The Bench Test Unit #2 is shown in Figure 3-2 and 3-3.

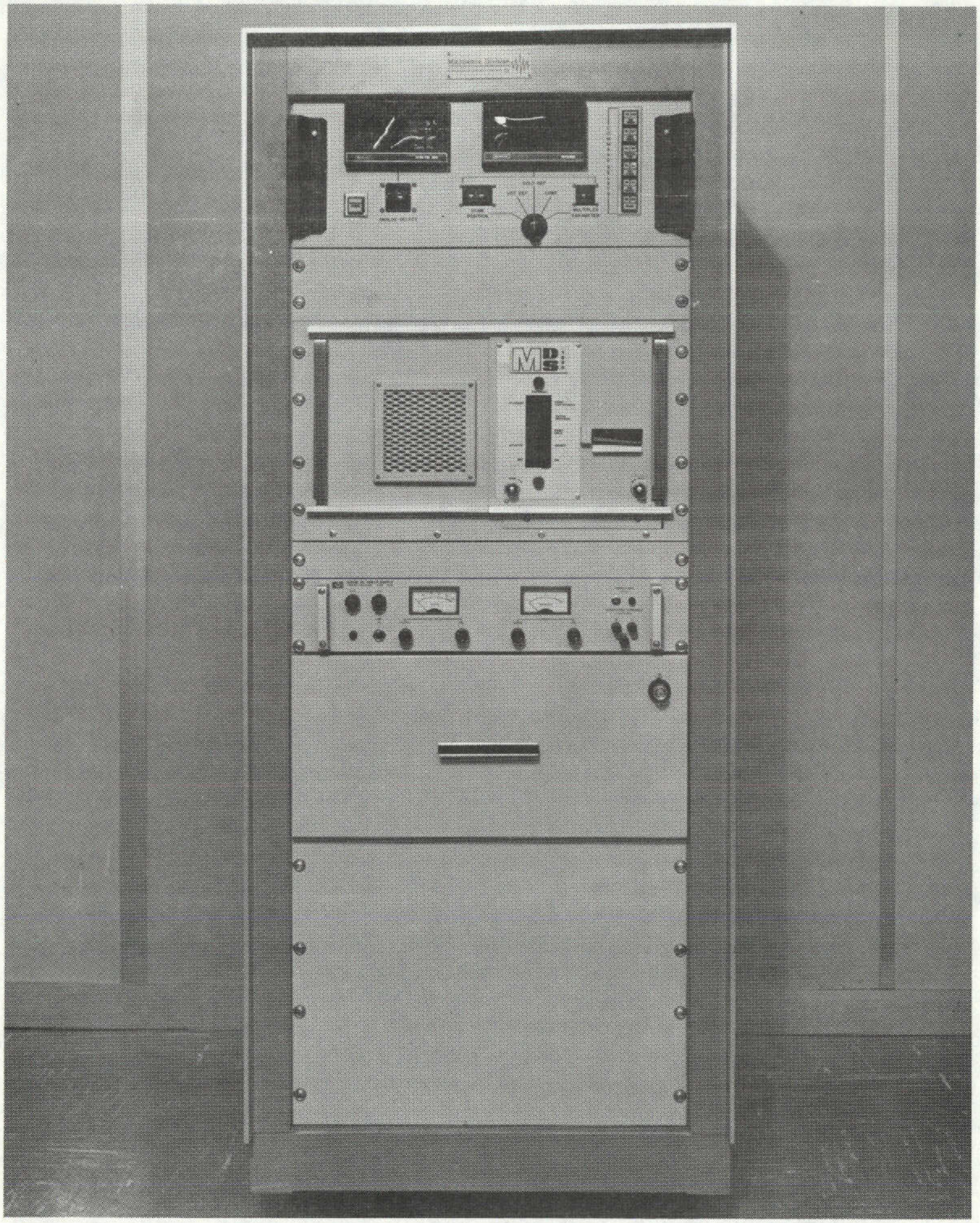


Figure 3-1. BTE No. 1

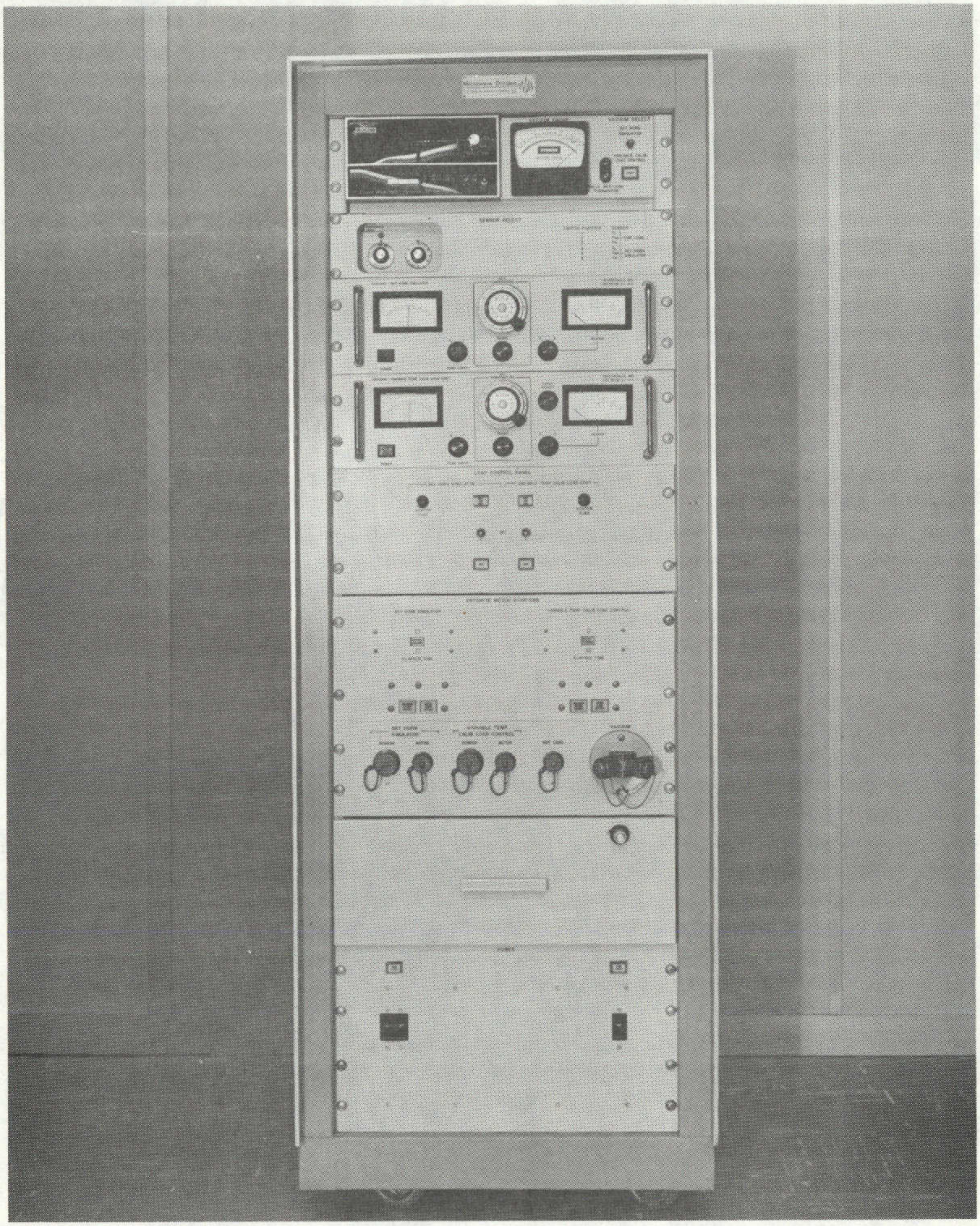


Figure 3-2. BTE No. 2

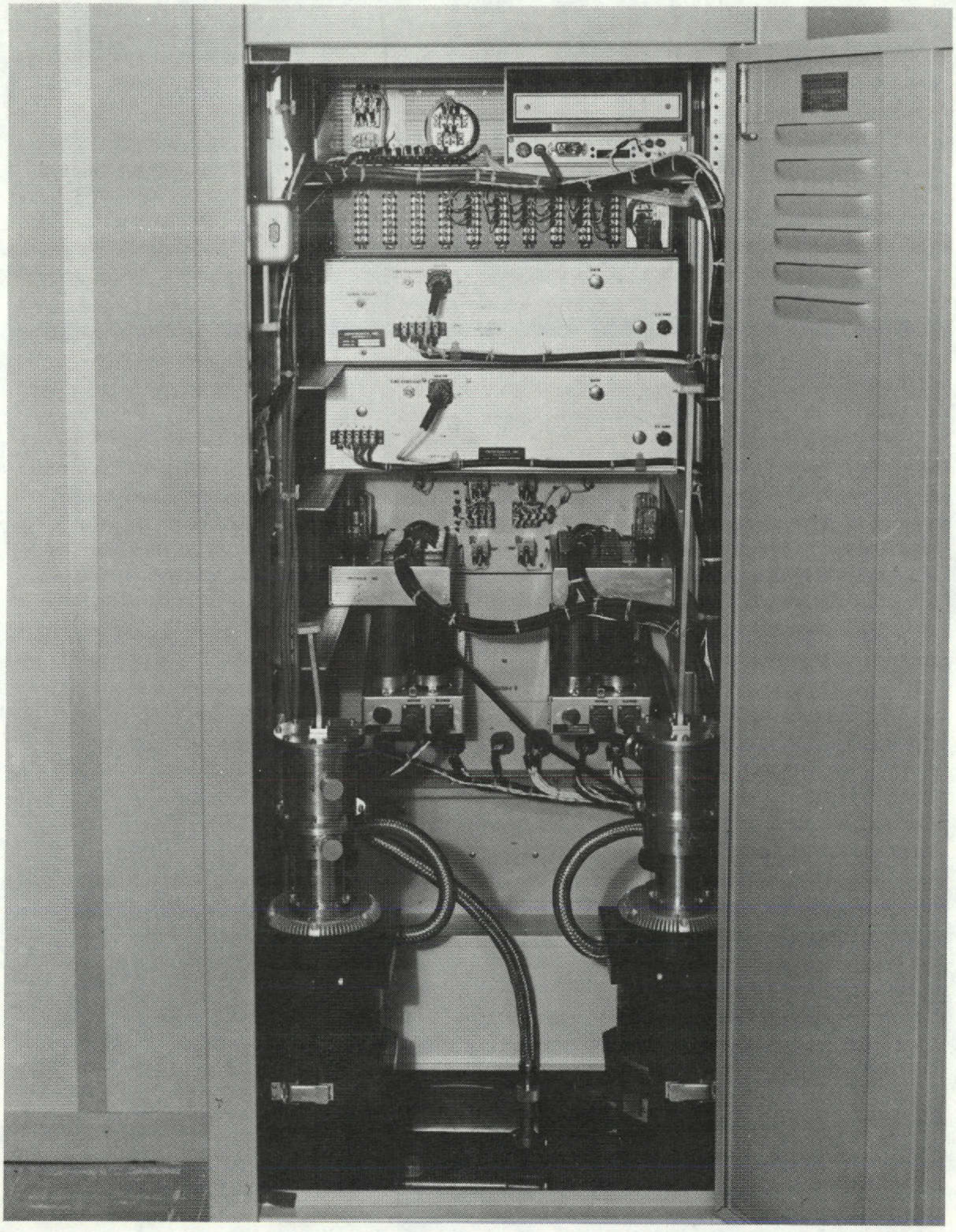


Figure 3-3. BTE No. 2 - Rear View

Appendix A

ENGINEERING TEST REPORT
EMSR-E ENGINEERING THERMAL BALANCE TEST

A.1 INTRODUCTION

Prior to performing the ESMR-E thermal vacuum test (MD-PROC-8022B) on the protoflight model, an engineering thermal balance test was performed. This engineering test was conducted in the TRW 5' x 6' thermal vacuum chamber equipped with an LN_2 cooled shroud. A bank of heat lamps was used to heat first the cover side and then the antenna side of the ESMR. In each case the temperatures were allowed to reach steady state followed by an eclipse where the heat lamps were turned off. The ESMR was instrumented with 41 thermocouples to record the temperatures. The chamber pressure was maintained at 10^{-5} torr or lower throughout the test.

A.2 EQUIPMENT AND TEST SETUP

The test was performed during November 1971 in the TRW horizontal 5' x 6' thermal vacuum chamber located at TRW Systems, Redondo Beach, California.

The chamber interior was completely covered by a black LN_2 cooled shroud capable of being maintained at -290°F. Chamber vacuum was maintained by means of a diffusion pump and measured with an ion gauge.

The ESMR was instrumented with 40 copper-constant in thermocouples using 28 gauge wire. Eight other thermocouples (T/C) were used to monitor the temperatures of the ESMR power cable bundles, the lamp fixture, the collar and the LN_2 shrouds. The T/C locations are listed in Table 1. All were attached with a small piece of tape or a small amount of RTV where the tape could not be used. ESMR power was supplied by the AGC/MD Bench Test Unit #1 Model 1371701-1. Hermetically sealed feed-throughs were provided for the T/C and power cables. All temperatures were recorded on two Esterline-Angus multipoint recorders.

The heat lamp bank was mounted in the top of the horizontal chamber. The ESMR was positioned horizontally with the irradiated surface 25 inches below the lamp frame. The ESMR was suspended from the top of the chamber by thin aircraft cables connected to the four handling eyelets. For the inverted position with the array facing upward, small fiberglass extensions were fabricated and mounted to each of the four handling holes and had eyelets in them for the suspension cables.

A rectangular collar or "picture frame" about 4 inches wide on a side was fabricated from sheet aluminum and covered with about 1/2" of super insulation. This collar was mounted around the upper edge of the ESMR to prevent irradiation from the heat lamps from reaching the edges of the ESMR. This produced a more orbit-like situation with the external heat incident on only one surface and all other surfaces radiating to the cold shroud as they would to space.

The power cables and T/C bundles were wrapped with super insulation to prevent them from having a signficant thermal effect on the ESMR during the test.

Five IR radiometers were used to measure the intensity and uniformity of the irradiation from the lamps. Four radiometers were placed adjacent to the four edges of the ESMR and one was placed near the center. The output of the radiometers was connected via a feed-through to voltmeters outside the chamber. Calibration curves were provided to convert voltage into heat flux.

The lamp bank consisted of two separately controlled arrays. By monitoring the radiometer outputs and adjusting voltage to each lamp array some control over uniformity could be exercised.

A.3 TEST PROCEDURE

The first phase of the test was with the ESMR mounted in the chamber with the covers facing upward and being irradiated by the lamps. The chamber was evacuated to 10^{-5} torr or lower. LN_2 was introduced into the shroud and the lamps turned on at a low intensity. As the temperature of the shroud dropped, the voltage to the lamps was increased. As the temperatures of the shroud and ESMR began to stabilize, the lamp voltage was adjusted to produce approximately a 100°F temperature on the covers while maintaining a fairly uniform intensity. Temperatures were recorded on the multipoint recorders constantly during the stabilization process and recorded on data sheets each half hour. Steady state was defined as less than 1°F change in one hour. Once steady state was reached the final temperatures were recorded and the heat lamps turned off to start the eclipse. The ESMR power remained on. The eclipse lasted one hour, during which temperatures were recorded. At the end of the eclipse the lamps were turned on to help return the ESMR to room temperature and the LN_2 was purged from the shroud. After the ESMR and shroud returned to near room temperature the chamber was allowed to return to ambient pressure slowly.

The ESMR was then withdrawn from the chamber and inverted so that the array faced upward toward the heat lamps. The above test procedure was then repeated. After 40 minutes of the eclipse the ESMR power was turned off in order to approximate an orbital eclipse with power off. The duration of the power off eclipse was 30 minutes.

The bottom heated test was concluded following the sequence described for the top heated test.

This concluded the engineering balance test.

A.4 RESULTS AND CONCLUSIONS

The steady state test temperatures are shown in Table I for both cases. The radiometer readings for the heat lamps are shown in Table II. Lamp intensity was adjusted to maintain approximately 100°F on the electronics cover for the top heated case and 100°F on the array for the bottom heated case. The 100°F temperature approximated the peak temperature for these locations based on orbital prediction.

Maintaining these outer surface temperatures at the orbital peaks long enough for the entire ESMR to reach steady state with power on was conservative from a verification standpoint since these surfaces reach these temperatures only periodically during orbit. Therefore, this test substantiated the high temperature performance of the thermal design of the ESMR since all components remained within acceptable temperature limits.

The ESMR-E computer model was used to simulate the ESMR in the chamber. Expected temperatures were calculated prior to the test and are also shown in Table I. The computer model did not have sufficient nodes to provide a temperature for each T/C location. A uniform heat input was used in the calculations. Fairly good agreement between expected and measured data can be seen for the bottom heated case. For the top heated case the fact that some of the internal components were calculated to be 40° to $45^{\circ}F$ compared with measured temperatures of 90° to $95^{\circ}F$ and 25° to $40^{\circ}F$ calculated for the array face compared to a measure of 55° to $65^{\circ}F$ indicated that some of the internal thermal paths of the model and possibly the array surface properties were incorrectly modeled.

The temperature gradient across the phase shifters was monitored during the test. For the top heated case the gradient was $3^{\circ}F$ from center to either end. This was well within acceptable limits. For the bottom heated case the maximum gradient was $17^{\circ}F$ between the center and the -Y end of the phase shifters (87° center, 70° end) and $8^{\circ}F$ between the center and the +Y end (87° center, 79° end). (All axis designations refer to spacecraft axis system.) This rather high asymmetrical gradient can be explained by the fact that the lamp intensity was 7% lower on the -Y side compared with the +Y side and that the DC/DC converter which was $133^{\circ}F$ for this case was located on the +Y side. These two factors combined to cause asymmetric heating. The temperature of $133^{\circ}F$ for the DC/DC converter had a stronger influence on this gradient during the test than it will in orbit since the maximum orbital temperature is expected to be $117^{\circ}F$.

Figures I and II show the temperature histories for various sections of the ESMR during the two test eclipses. Figure I shows the 60 minute eclipse for the top heated case. Figure II shows the 40 minute eclipse for the bottom heated case followed by the 30 minute eclipse with ESMR power turned off. The power-on portion of this eclipse is shown with solid lines and the power-off portion is shown with dashed lines.

The deployed position in orbit is most clearly simulated by the bottom heated eclipse. In the deployed position in orbit the bottom or array face receives solar radiation just prior to passing into the earth's shadow. This produces array temperatures near $100^{\circ}F$ as in the bottom heated test case. The orbit occulation time is approximately 35 minutes. Figure II shows that the ESMR electronics section decreased in temperatures approximately $28^{\circ}F$ during the first 35 minutes of the eclipse in the chamber. The phase shifters decreased about $24^{\circ}F$ for the same period. This data can be compared with the predicted decrease for orbit occulation of about $15^{\circ}F$ for each section. However, in orbit the ESMR absorbs approximately 75 watts due to earthshine during occulation which tends to decrease the temperature decline. On this basis the temperature decrease of 24° to $28^{\circ}F$ in the chamber indicates that the thermal design will perform satisfactorily during orbit occulation with power on.

A power-off eclipse test starting with steady state temperatures was not performed. However, after the 40 minute power-on eclipse for the bottom heated case the power was turned off and a 30 minute power-off eclipse was performed. The start temperatures for this eclipse was within $10^{\circ}F$ of those calculated for orbit with the exception of the DC/DC converter. The DC/DC converter did not have sufficient time to cool before starting the eclipse. The electronics, radiometer and phase shifter sections registered a temperature decrease of about $30^{\circ}F$. Orbital calculations showed a decrease of about $14^{\circ}F$ for these areas. This is similar to the power-on eclipse in that the presence of the earthshine would account for the difference between the orbit and chamber eclipses. Also, during the chamber eclipse the temperatures did not fall below acceptable limits. Hence, the thermal performance of the ESMR during a power-off eclipse is considered to be satisfactory.

Comparison of the expected test calculated temperatures with the measured data shown in Table I indicates that upgrading of the computer model was desirable before final orbital temperature predictions were made. This was especially evident in the top heated case in the area of the electronics and radiometer sections. By examining the thermal paths in these areas it was found that conduction paths formerly considered to be insignificant must be included in the model. Also, other conduction paths and some radiation paths had been estimated too low. Finally, it was determined that the effective $\bar{\epsilon}$ of the array face was actually lower than that used in the calculations. It appears now that the $\bar{\epsilon}$ of the array is about 0.50 instead of the 0.57 that was based on calculations and some inconclusive laboratory measurements.

With a computer model incorporating the above changes, final temperatures were calculated for the test conditions. These results are also shown in Table I. It can be seen that all areas are within $10^{\circ}F$ of the test temperatures.

As a result of this thermal balance test the corrected computer model is considered to be sufficiently accurate for predicting final orbital flight temperatures for ESMR-E.

Final orbital temperature calculations have been made using this refined model and are presented in the appendix. For the deployed position all temperatures are well within operating limits for all of the equipment. The low temperatures for the deployed power-off condition are well above the minimum start-up requirements. All temperatures for the stowed power-off condition are safely within the range that could have an effect on any of the ESMR components. The thermal ΔT's both across and over the honeycomb panel are not expected to cause warpage that could significantly affect the ESMR.

Also shown in the appendix are the final surface properties used in the orbital calculations. These data were determined from both thermophysics measurements and the thermal balance temperature data.

Based on both the test data and analytical results it is evident that the ESMR-E will experience acceptable temperature limits throughout the Nimbus-E mission.

Table I

Thermocouple Locations and Steady State Temperature Data

T/C No.	Location	Top Heated ~ °F S.S. T/C Readings	Top Heated ~ °F Calculated Expected Temps	Top Heated ~ °F Calculated Final Temps	Bottom Heated ~ °F S.S. T/C Readings	Bottom Heated ~ °F Calculated Expected Temps	Bottom Heated ~ °F Calculated Final Temps
1	Outside phase shifter cover, center	102	110 - 115	104	64	45 - 50	69
2	Outside phase shifter cover, + Y axis	101			67		
3	Outside phase shifter cover, -Y axis	96			68		
4	Outside electronics cover, center	98	90 - 95	107	76	60 - 65	77
5	Outside electronics cover, over DC-DC converter	101			85		
6	Outside electronics cover, over Gunn oscillator	94			75		
7	Inside of side rail next to phase shifter, (+Y)	77			85		
8	End phase shifter coil, +Y	84	90 - 95	84	79	70 - 75	84
9	Center phase shifter coil, (#045)	87	95-100	89	87		90
10	End phase shifter coil, -Y	84	90-95	84	70		80
11	Inside of side rail next to phase shifter (-Y)	79			65		
12	Inside front cross rail center, center	83	40-45	83	93	95 - 100	99
13	Circuit board A15 (center board)	92	40 - 45	83	100		99
14	Switch driver transistor	110			113		
15	DC-DC Converter, top	115	105 - 110	122	133	140 - 145	130
16	Circuit board A6	94	40 - 45	83	99	95 - 100	99
17	Power transistor mounted on center open rail	84	40 - 45	83	99	95 - 100	99
18	Gunn Oscillator	90			109		
19	Gunn Oscillator Radiator	91			109		
20	New DC-DC Board between capacitors	120			*		
21	Center cross rail between thermalloys	91	40 - 45	83	100	95 - 100	99
22	Mixer, top	94	40 - 45	83	112	95 - 100	99
23	Cold horn	68			88		
24	Rear deck, +Y	127	115 - 120	130	35	10 - 15	28
25	Collar, front	-50			-100		
26	Outside rear cross rail, center	86			85		
27	Rear deck, locating block	75			84		
28	Rear edge, center	50			63		
29	Outside of foam, next to phase shifters, -Y	65			70		
30	Outside of mounting, interface, +Y	78			86		
31	Outside of foam, side, rear, +Y	76			91		
32	Antenna face, -X, +Y corner (base)	54	25 - 30	53	104	95 - 104	101

* = Defective thermistor connection

Table I (Cont.)

Thermocouple Locations and Steady State Temperature Data (cont.)

T/C No.	Location	Top Heated ~ °F S.S. T/C Readings	Top Heated ~ °F Calculated Expected Temps	Top Heated ~ °F Calculated Final Temps	Bottom Heated ~ °F S.S. T/C Readings	Bottom Heated ~ °F Calculated Expected Temps	Bottom Heated ~ °F Calculated Final Temps
33	Antenna face, -X, Center (Base)	63	25 - 30	58	100	95 - 104	101
34	Antenna face, center, center (base)	63	35 - 40	58	100		105
35	Antenna face, center, center (surface)	57	30 - 35	58	103		105
36	Antenna face, under DC-DC (base)	63	35 - 40	58	110		105
37	Antenna face, under rear deck (surface)	17	15 - 20	34	94		99
38	Inside side rail, next to DC-DC	95			104		
39	Under DC-DC Mounting Screw	88			113		
40	Front edge cap, center	65			81		
41	Center phase shifter coil (#009)	86	95 - 100	89	90	70 - 75	89
42	Power Cable, +Y	75			58		
43	Power cable, -Y	73			54		
44	Collar, right side of chamber	-100			-137		
45	Back wall of shroud	-290			-300		
46	Main shroud, top front	-295			-295		
47	Door shroud	-273			-295		
48	Lamp fixture	-4			-6		

Table II

STEADY STATE IR RADIOMETER READINGS

Top Heated

Radiometer No.	1	2	3	4	5	
Serial No.	15	16	17	21	Special	
Location	Front	Right (-Y)	Rear	Left (+Y)	Center	(Axis location refers to S/C axis system)
Voltage	1.250	1.171	1.231	1.179	1.258	
Absorbed energy BTU/Hr ft^2	320	295	306	292	354	
Incident energy BTU/Hr ft^2	352	324	336	321	390	Ave. = 345

Bottom Heated

Location	Front	Right (+Y)	Rear	Left (+Y)	Center	
Voltage	1.085	1.022	1.068	1.027	1.084	
Absorbed energy BTU/Hr ft^2	221	212	217	198	216	
Incident energy BTU/Hr ft^2	242	233	239	218	238	Ave. = 234

THERMAL BALANCE TEST
ECLIPSE DATA
TOP HEATED

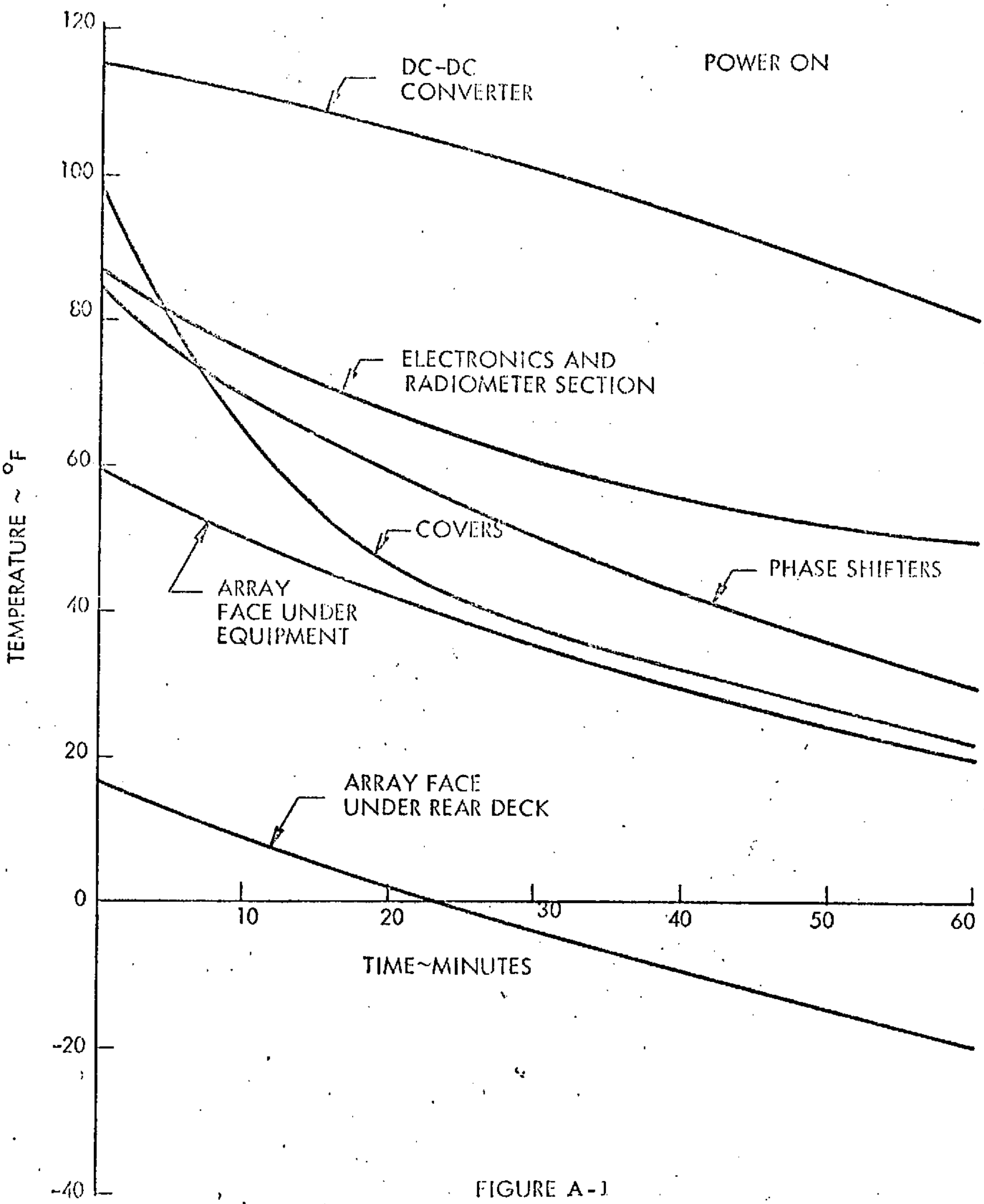


FIGURE A-1

THERMAL BALANCE TEST
ECLIPSE DATA
BOTTOM HEATED

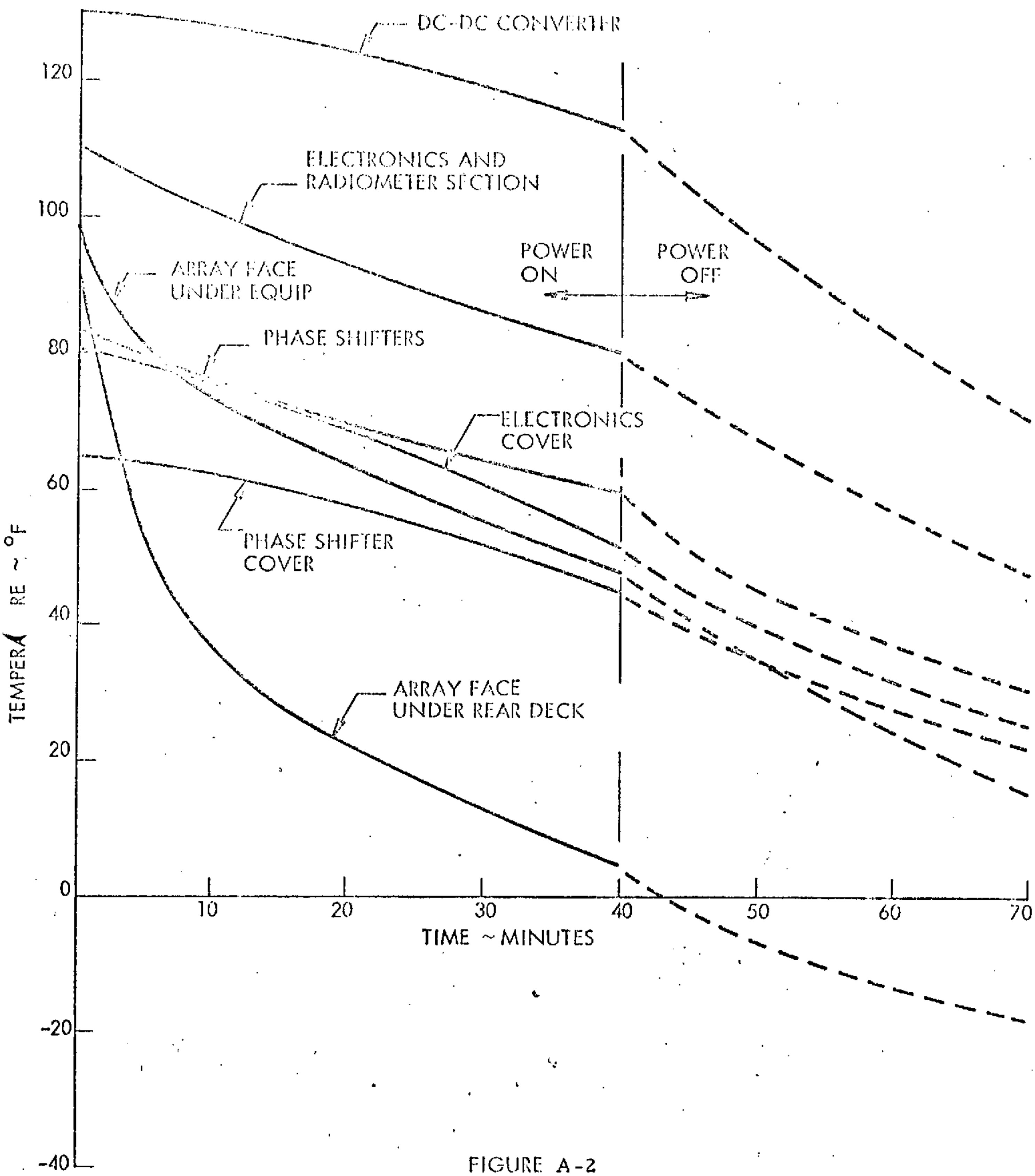


FIGURE A-2

V - APPENDIX

ESMR-E FINAL ORBIT TEMPERATURE SUMMARY

(Includes Results of Thermal Balance Test)

	Orbit - Max. Min.		
Location	Deployed Power On	Deployed Power Off	Stowed Power Off
Phase Shifters	86 - 65°F (30-18°C)	63 - 41°F (17-5°C)	61 - 43°F (16-6°C)
ΔT Across Phase Shifter	7°F (4°C)	5°F (3°C)	5°F (3°C)
Phase Shifter Cover	111 - 50°F (44 - 10°C)	90 - 28°F (32 - -2°C)	81 - 28°F (27 - -2°C)
Electronics and Radiometer Section	84 - 65°F (29 - 18°C)	57 - 39°F (14-4°C)	46 - 35°F (8 - 2°C)
Electronics and Radiometer Cover	103 - 49°F (39 - 9°C)	82 - 25°F (28 - -4°C)	69 - 23°F (21 - -5°C)
DC-DC Converter	117 - 105°F (47 - 41°C)	53 - 41°F (12 - 5°C)	44 - 37°F (7 - 3°C)
Antenna Face	85 - 41°F (29 - 5°C)	66 - 30°F (19 - -1°C)	56 - 30°F (13 - -1°C)
Max ΔT across Honeycomb	9°F (5°C)	10°F (6°C)	6°F (3°C)
Max ΔT over Antenna Face	16°F (9°C)	11°F (6°C)	16°F (9°C)

FINAL SURFACE FINISH PROPERTIES

Covers: D4D Aluminum Paint

$\alpha_s = 0.245$

$\epsilon = 0.280$

Antenna Face:

$\alpha_s = 0.66$

$\epsilon = 0.50$

Side Edges: Foam Insulation